

# MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY

VOL. 59, No. 7  
W. B. No. 1053

JULY, 1931

CLOSED SEPTEMBER 3, 1931  
ISSUED OCTOBER 5, 1931

## LIGHTNING INVESTIGATION AS APPLIED TO THE AIRPLANE<sup>1</sup>

By A. O. AUSTIN, Chief Engineer, The Ohio Insulator Co.

While the lightning hazard to airplanes or any aircraft is very small compared to many everyday risks, this hazard receives much attention. Although lightning has caused a few fatalities, it would seem that many cases of trouble due to other causes have been unjustly charged to lightning. Once the effect of lightning upon the pilot or plane is recognized, steps can be taken to materially reduce if not eliminate the hazard, although this may be small at most.

The studies made in the high voltage laboratory of the Ohio Insulator Co. for Ward T. Van Orman in testing out his protection for free balloonists, and the series of tests run on planes and other equipment furnished by Popular Mechanics, provide some rather interesting information. An attempt will be made to cover some of these studies briefly.

Since the tests run in connection with free balloons illustrate certain phases of the subject to better advantage than those upon airplanes, this matter will be treated first.

In running the series of tests balloon baskets, small size balloons, model airplanes as well as full sizes air planes were placed between a large electrostatic condenser and ground on the test field. The condenser may be regarded as a charged cloud and a discharge taking place between this cloud and ground can be made to strike the equipment under test. Figure 1 shows a discharge taking place from this condenser to ground, the photograph being taken by a synchronized camera.<sup>2</sup>

In general the hazards from lightning may be divided into two classes:

(A) Electrical or physical shock, which may affect the pilot and passengers.

(B) Those hazards which damage the plane or aircraft. It would seem that the hazard due to the direct electrical or physiological effect of lightning upon the pilot or passengers should receive first consideration, rather than the damage to the aircraft. Unfortunately it is very difficult to obtain information upon this point owing to the variation in the personal element itself, and the hazard of making studies which may be exceedingly dangerous. It may be said, however, that as the size of aircraft increases the direct danger to pilot or passengers tends to decrease providing ordinary precautions are taken in the design and construction of the aircraft. This is due to the greater distance of the crater or point of contact of the lightning from pilot and passengers.

*Hazards to the plane or aircraft.*—These hazards may be classified as follows:

1. Fire hazard due to ignition of combustible material used in the construction of the plane.
2. Fire hazard due to ignition of explosive gases.

3. Weakening or destruction of metal or other parts due to current in the discharge.

4. Breakdown of insulation in the ignition system.

5. Back fire or preignition.

6. Damage to instruments.

7. Damage to rotating parts due to passage of current.

8. Sudden change in pressure on adjacent surfaces.

*Electrical or physiological shock to pilot or passengers.*—The experience of free balloonists throws considerable light upon the hazard due to shock, and means of protection. The fatalities in Belgium and Pittsburgh of recent years caused Van Orman to give this matter considerable attention.

In the Pittsburgh race Van Orman's balloon was struck by lightning while at an altitude of 3,000 feet and set on fire, and Morton, who was with him in the basket, was killed by the stroke. The 26 R. C. A. portable loop radio set which was between Van Orman and Morton appeared to be badly damaged. However, an investigation showed that the set was not damaged electrically. Van Orman was apparently conscious for a short time after the stroke. He then lost consciousness and apparently remained in a stunned or dazed condition for five or six hours after the parachuting balloon struck ground.

Wollam and Cooper in the *City of Cleveland* had a somewhat similar experience, the stroke of lightning apparently passing over the surface of Cooper's leather jacket or suit which was wet at the time. The shunt path provided by the suit apparently saved Cooper's life, although he was badly burned by the stroke. Wollam escaped uninjured and attempted to lift Cooper and his parachute out of the basket, but was unable to do so. Cooper apparently is the only known person to suffer a heavy direct stroke and still live to tell about it.

These incidents show that a stroke of lightning may be very close to a person without causing any serious injury. Had the pilots been subject to the same condition while flying an airplane, it is possible that they might have lost control of the plane causing it to crash.

Figure 2 shows the basket used on the *City of Cleveland* balloon which was struck while the balloon was at least 5,000 feet in the air.

The photograph shows the basket with a dummy in place being subjected to an artificial lightning discharge. The steel cables from the ring to the basket were not bonded to the reinforcing wires which were used in making up the basket. It is possible that had bonding been carried out, the results might have been quite different.

In the tests shown in Figure 2, the collapse of the electrostatic field caused an induced potential of over 25,000 volts between the dummy and the lower part of the basket. While the energy is not large, the discharge might tend to frighten or startle one similar to a shock one receives in coming in contact with a metal object

<sup>1</sup> Communicated by W. T. Van Orman, Goodyear Zeppelin Corporation, Akron, Ohio.

<sup>2</sup> All figures are grouped on inset sheets at end of article.—Editor.

after picking up a charge in walking over a carpet in cold dry weather.

Figure 3 (not reproduced) shows the metal reinforcing wire fused due to the discharge of lightning. It will be noticed that the horizontal wire crossing the vertical wire has been burned in two, as well as some of the basket material. An examination of the basket showed a large number of burns where the reinforcing wires crossed each other.

Figure 4 shows a test on Van Orman's lightning protecting scheme. The protection consists essentially of a cage formed by conductor hanging freely. These conductors are bonded at the top and part way down, but left entirely free at the bottom so as not to interfere with landing or parachute jumps from the basket. The conductors forming the shunt path are moved outward from the basket a short distance. The cable supporting the basket to the ring has been replaced with rope. It would seem that had this device been used in the flights in Belgium and Pittsburgh, the fatalities due to direct stroke would have been eliminated.

Apparently there is little difficulty in shunting the main discharge, but there is some question as to how far the discharge should be from the pilot so that he will not be stunned or frightened to the extent of losing control. The baskets in racing balloons are rather small, and anyone in the basket must of necessity be very close to any discharge striking the basket. Should the Van Orman cage give the necessary protection for direct hits, it would go to show that the protection to pilot or passengers in an airplane may be easily provided by shunting the discharge a short distance to one side.

*Danger of direct hit.*—Many people believe that a balloon or airplane should not be subjected to a lightning stroke while flying, since there is no direct ground connection. Any object which has a greater conductivity than the air or a greater electrostatic flux carrying capacity will tend to disturb the electrostatic field and will cause a discharge in the immediate vicinity to take a path along the object.

*Effect of construction upon a stroke of lightning.*—In running the tests on the Van Orman cage, an attempt was made to protect the balloon. If the gas in the balloon is free from air, lightning will not cause it to explode although the balloon may be set on fire. If an explosive mixture is present in the balloon, an explosion may take place due to the ignition of the mixture.

*Difference between a wet and a dry balloon.*—In the study of high voltage phenomena, particularly those applicable to transmission line structures using wood, it was believed that there would be a considerable difference between a wet and a dry balloon. The tests were very interesting in this connection, as they go to show that while there might be a considerable difference in aircraft which is constructed of metal and that primarily of nonconducting material, when dry there would be little difference where the latter was wet. This difference is undoubtedly due to the increase in electrostatic capacity due to the presence of water.

Figure 5 shows a hydrogen filled balloon being subjected to an artificial stroke of lightning. The balloon has a conductor attached approximating a long antenna, hanging from the lower side. A number of discharges were applied to the balloon similar to that in Figure 5. All of these discharges struck to the upper part of the conductor attached to the balloon, and then from the lower end of this conductor to ground.

As soon as the balloon was wet, however, conditions were entirely changed, the performance being similar to that shown in Figure 6. The discharges instead of going directly to the antenna and then to ground, struck the surface of the wet balloon. The discharge in Figure 6 is apparently passing along the surface, which destroyed the balloon in all cases. The discharge invariably burned the rubber and set the escaping gas on fire. Had the photograph been taken a fraction of a second later, the balloon would have been collapsed, the duration of the arc shown in the photograph being less than one half microsecond.

These tests go to show that there is little or nothing to be gained electrically by the use of nonconducting material in the aircraft structure where the material becomes wet, as the electrical fields set up are not materially different.

A discharge striking conducting material adjacent to inflammable material is likely to set the latter on fire. There are many cases which illustrate this point. Owing to the tendency of a discharge to strike a wet balloon, it was evident that it was necessary to remove the point of contact of any conducting system some distance from the balloon. While this is a distinct disadvantage to racing balloons, owing to increased weight, the tests are very interesting as they show the tendency of the wet fabric in diverting a discharge.

Figure 7 shows a discharge to ground some few feet distant from a balloon equipped with a cage or lightning rods. In Figure 8 the balloon has been wet. While there was some tendency for the balloon while dry to attract the arc, the point of discharge was too great, so that the arc struck to ground. In Figure 8, however, the field set up by the wet balloon was of sufficient magnitude to attract the discharge. The discharge followed the shunt path, then continued from the lower end of the cage to ground. Without the shunt path, the wet balloons were invariably set on fire by the direct stroke. In some cases the fabric seemed to be only slightly damaged. The escaping gas, however, was frequently ignited by the stroke, causing destruction of the balloon unless quickly extinguished.

*The probability of a direct hit.*—In the case of free balloons or blimps there would undoubtedly be a considerable difference between the wet and dry conditions in attracting a discharge in the vicinity. In other aircraft as now constructed, however, there would be little difference, wet or dry. In the tests on models placed near the path of discharge it was evident that the path of discharge was diverted an appreciable distance by the presence of the plane. It would seem that the probability of being struck would increase approximately as the square of the greatest linear dimension.

The nature of the electrical field, the polarity of the discharge, and the direction of the axis of the aircraft relative to the general path of discharge, are all factors which make it difficult to predict the effect of size in increasing the probability of direct hits. Figures 9, 10, 11, and 12 (fig. 10 only reproduced) show typical discharges to model planes showing the probable points of contact of the stroke.

Figure 13 shows a positive discharge of limited capacity striking a model Zeppelin. The discharge was not sufficient to cause the arc to continue to ground, but illustrates the effect of a large body free of ground. Immediately following the first discharge, another discharge was applied of sufficient magnitude to cause a discharge

not only to the model Zeppelin but from the rudder to the ground.

It is interesting to note that in all of the tests the fabric used on the Zeppelin and that on the fabric-covered duralumin airplane was not ignited by the discharges. This goes to show that the fire hazard is negligible where a path of high electrical conductivity is provided.

It would seem that the effective increase in size and the use of metal in the present construction of airplanes should do much to minimize the lightning hazard, even though little or no attention is given to protection.

A direct hit to the plane may possibly affect the pilot or passengers in one of the following ways:

- (a) Direct hit.
- (b) By forming a path for the discharge between conducting objects.
- (c) Shock from induced charge.
- (d) Sudden change in air pressure.
- (e) Severe sound or pressure waves.
- (f) Currents induced in the body by an electromagnetic field.
- (g) Hazard due to the effect of intense light upon the pilot.

While the danger from some of these hazards may be absent in many planes, they can be largely reduced if not entirely eliminated in others by proper attention to details of construction, or by applying a protecting scheme which will establish the path of discharge at a distance from the pilot.

(a) *Direct hit.*—In general the possibility of a direct hit to the pilot is exceedingly small even in the low wing monoplane with open cockpit. The tests showed that the discharges would enter or leave through the propeller or nose, rudder, wing tips, or landing gear. A lightning rod projecting above and to one side of the pilot would insure the diverting of the stroke even though the pilot's head projected well above the fuselage. In large planes or Zeppelins the points of contact of the stroke would be considerably removed from the pilot or passengers, so that it would appear that the danger from direct stroke may be even less than that in the ordinary dwelling during an electrical storm.

(b) *By forming a path for the discharge between conducting objects.*—A discharge of lightning may carry a current far in excess of that available in any of the laboratories used for the production of artificial lightning. The fused wire in the basket shown in Figure 2 (not reproduced) can not be duplicated with the heaviest lightning discharges in the laboratory. Records taken at the forest rangers' stations show that a stroke of lightning may be sufficient to fuse a No. 14 copper wire. Tests on aerials have shown that wire of larger size is fused, all of which indicate currents exceeding several hundred thousand amperes.

The impedance afforded by conductors with this very high rate of discharge will cause a considerable drop in potential. This drop in potential causes the current to divide into multiple paths, the drop in voltage being sufficient to cause the bridging of appreciable air gaps where the impedance is not very large. It is therefore essential that the most careful attention be given to bonding. In order to reduce the impedance it is well to distribute the conductor in several parallel paths. This reduces the reactance and the voltage induced by the high rate of discharge.

It is evident that should the pilot come in contact at two points along a conducting member, he is likely to be subject to shock. The thorough bonding, the use of a

low impedance multiple path as far away from the pilot as possible, together with a single point of contact with conducting material will eliminate the danger of shock from drop in potential due to the passage of exceedingly large currents.

(c) *Shock from induced charge.*—A pilot in an open cockpit may be subjected to an induced charge due to the collapse of the electrostatic field. It would seem that this charge would amount to but little providing the discharge did not cause the pilot to become frightened so as to lose control. The complete shielding afforded by metal cabin planes completely eliminates the effect of the induced charge due to the collapse of the electrostatic field. The same applies to Zeppelins.

(d) *Sudden change in air pressure.*—The intensity of lightning varies greatly for different strokes. It would seem, however, that the very severe discharge causes a rapid heating of the air and an increase in pressure in the immediate vicinity. The pressure set up where the air is free to expand is not as great as originally supposed. The fact that three balloonists have come through storms where the stroke was within a foot or two of them would indicate that the hazard from this source is not serious, even for the very heaviest discharges where the path can be moved out a few feet from the pilot.

(e) *Severe sound or pressure waves.*—The effect of the severe sound and pressure waves may be responsible for the shock suffered by pilots and others who have been within a few feet of lightning strokes. The duration of the effect seems to vary considerably with the individual, and may cause effects somewhat similar to those suffered from shell shock. Many of the factors producing shell shock are present although there are others in addition. The severity reduces rapidly with distance. It would therefore seem that using a construction which removed the point of contact between lightning and plane well away from the pilot will do much to eliminate any serious effects which may cause the pilot to lose even temporary control.

The pilot can, of course, be easily protected from sound or pressure waves by providing a suitable compartment or other sound-absorbing equipment.

(f) *Currents induced in the body by an electromagnetic field.*—A stroke of lightning may consist of a single discharge or several discharges within a very short space of time. The strength of the electromagnetic field will vary directly as the current in the discharge, and inversely as the distance. A current of 400,000 amperes in a stroke will produce a field of 2,620 maxwells at 1 foot distance; 262 maxwells at 10 feet distance, and 131 maxwells at a distance of 20 feet.

Any change in the electromagnetic field passing through either high or low resistance material will induce a voltage and current. The induced voltage and current will depend upon the rate of change in the magnetic field. It is evident that the lines of force passing through a person will induce currents, the action being similar to that in a high-frequency furnace. Several strokes in rapid succession may induce a greater current or potential than a single stroke of higher maximum magnitude but having a slower rate of change.

While it is possible to screen the electrostatic field, it is practically impossible to effectively screen the electromagnetic field so as to prevent the lines of force passing through objects in the vicinity of the field. The field may be set up by the current of a portion of the discharge in the air, or in a conductor in the aircraft. It would seem that the heaviest discharges taking place close to a person

may induce enough potential and current to effect the system, or at least paralyze the nervous system temporarily.

A study of the factors affecting the induced potential and current goes to show that the electromagnetic field may be materially reduced by removing the shunt path from the immediate vicinity, and by forming multiple paths around the pilot or passengers so that the field set up by the current in one path tends to neutralize the field set up in the other. The fact that some people have not been affected although within a few feet of the discharge would indicate that a reduction of the field strength by an appreciable amount would entirely change conditions and provide protection even for the most severe strokes.

Further investigation may show that the induced current does not constitute a hazard. The magnitude of the voltage generated and the current induced for heavy strokes in the immediate vicinity, however, would indicate that the possibility of affecting at least the nervous system can not be ignored without very definite proof to the contrary.

Although little has been accomplished in determining whether or not the shock or stunning effect is primarily due to electrical causes or to physical conditions similar to those producing shell shock, the same method will improve conditions for either case—which consists primarily in initiating the point of contact to the stroke as far away from the pilot as possible.

(g) *Hazard due to the effect of intense light upon the pilot.*—The light from a stroke particularly at night may have the effect of blinding the pilot when passing through the line of vision. At night the iris is wide open, and it is possible that the ultra-violet light might have some effect upon the pilot for a discharge striking the nose of the plane. In most planes, however, the discharge would be to one side and above or below the direct line of vision. It is believed that the hazard from this cause is small. While intense light may have the effect of blinding the pilot for a short time, any serious effect due to ultra-violet light may be eliminated by the use of glass in the windows or goggles which would absorb any injurious rays.

While the effect of lightning upon the pilot or passengers undoubtedly causes the greatest and most uncertain hazards, there are other hazards to the plane or aircraft which need careful consideration.

1. *Fire hazard due to ignition of combustible material used in the construction of the plane.*—The fire hazard to the metal plane is negligible although intense heat exists at the point of contact with the lightning and the plane. The fire hazard is practically negligible even where material which will support combustion is used. Where an inflammable covering is used in contact with metal, the fire hazard is apparently negligible. Inflammable material which is readily ignited may be set on fire by the crater. The severe rush of air following the stroke has the effect of extinguishing the flame, the discharge being in the nature of an explosion. The rapid expansion of the gases even in the fabric apparently absorbs sufficient heat, which together with the blast of air following the discharge prevents ignition. This is particularly true where a fabric is used to cover duralumin or other metal. The heat conduction of the metal and the low resistance of the path afforded tend to not only absorb the heat but reduce the energy dissipated.

Figure 14 (not reproduced) shows the effect of artificial lightning upon the rudder. It will be noted that the

fabric has apparently been exploded at the points of contact, the fibers being torn apart, the effect being very similar to that of popping corn.

A rather severe series of tests run on a model Zeppelin covered with fabric showed that it was impossible to ignite this fabric with the artificial lightning. The history of Zeppelins has also indicated that this danger is small unless conditions approximate those of the gas-filled free balloons.

2. *Fire hazard due to ignition of explosive gases.*—A discharge may take place between conducting surfaces not properly bonded, or from isolated tanks or conductors separated from the bonded structure by small air gaps. The discharge may be produced by the release of a bound charge following the collapse of the electrostatic field, or due to the impedance drop in conductors making up the structure, or by the change in the electromagnetic field. These induced discharges are similar to those noticeable in the ordinary dwelling where a discharge takes place between wiring and conduit or fixtures following a stroke of lightning near by. Should these discharges take place in a pocket of gas, an explosion may result. It is therefore important to either thoroughly ventilate all pockets which may accumulate gas or to adopt a construction so that a discharge can not take place. Vents or openings for scavaging explosive gases should be protected with a screen similar to that used in a safety lamp.

3. *Weakening or destruction of metal parts due to current in the discharge.*—In aircraft having a metal structure there is ample conducting capacity so that a serious temperature will not be reached in any of the metal parts. However, should the construction be such that the current is confined to small members or to important connections having a high resistance, it is possible that the heating may seriously affect the structure and lower the mechanical strength. This is important, as some of the alloys are materially affected by a temperature far below the fusing point.

While the varnishing of the surfaces and joints together with the oxidation of the surface go to produce a joint of high resistance, it must be remembered that the riveting cuts through the edge and forms a path of low resistance. A number of point contacts formed in this way results in a joint of very low resistance so that little or no damage need be feared even though cross section of metal in good contact is small. Where metal parts simply come in contact or are held a short distance apart, considerable energy may be dissipated in the joint.

It would seem that the greatest hazard due to heavy current affecting the strength of metal parts is that due to control cables or stay wires in nonmetal planes. Discharges direct to the rudder showed a very appreciable rise of voltage on the control cable, although in the plane tested a small percentage of the current only was carried by the control cable—the major part going through the hinge and metal framework.

4. *Breakdown of insulation in the ignition system.*—Most of the ignition systems are fairly well insulated and have to withstand the relatively high voltages generated in the normal operation of the engine. Care should be taken so that conductors of the ignition system do not form a shunt path. In addition, the conductors should be exposed as little as possible. The ignition systems apparently are more immune from trouble than would generally be expected. This seems to be due to the fact that the rise in voltage is limited by the discharging of the spark plug either inside or outside the cylinder.

Figure 15 (not reproduced) shows the ignition system being subjected to a discharge of over 1,500,000 volts. The discharge is striking the spark plug and lead on one of the cylinders. A number of similar discharges apparently had no effect upon the magneto or other parts of the ignition system. A small shield placed over the plug easily diverted the discharge.

5. *Back fire.*—It is evident that a discharge striking a plug or lead may cause a back fire or the engine cylinder to fire out of turn. A series of tests were made with the engine running so that the discharge would strike the propeller or ignition system. The propeller used was wood with a metal shielding which ended some distance from the hub.

Figure 16 shows a discharge striking the end of the propeller. The discharge is then shown jumping from the metal shielding on the propeller to one of the spark-plug terminals, as these happen to end about in line with the end of the shielding. A number of discharges apparently had no effect although it appeared that the impulse from one cylinder was lost. The effect, however, was so slight as to leave this point in doubt. A small shield placed in front of the rod effectively drew all of the discharges. While the hazard is exceedingly small, it would therefore seem to be good insurance to prevent a discharge of this kind to the ignition system which might break down the insulation of leads or the magneto.

6. *Damage to instruments.*—During one of the endurance flights at Cleveland the plane was struck by lightning and the instruments so damaged that landing was made. An examination of the instruments did not show any electrical damage due to the conduction of current. There was an indication that the diaphragm in the instrument which was connected to the Pitot tube used for determining velocity might have been damaged by the pressure set up. In the tests which were run some time later it was evident that the Pitot tube might be a point of contact for the stroke, in which case sufficient pressure might be set up so as to destroy the rather delicate diaphragm. A sudden air pressure set up by the stroke in any other way might of course have produced the same effect.

Should it appear that there is danger to instruments from the pressure set up, it would be a comparatively easy matter to prevent this by placing a baffle in the line between the Pitot tube and the instrument, preferably with a surge chamber between the restriction and the instrument. Other instruments could be inclosed in a chamber with a window.

The electrical fields set up by a heavy discharge in the immediate vicinity may damage magnetic instruments or those in which an induced current may cause a breakdown of insulation. While electrostatic screening is comparatively easy, screening for the electromagnetic field is very difficult and it would follow that instruments which are likely to be damaged by a strong magnetic field should be so placed that the path of discharge in the frame or surrounding objects is removed as far as possible.

7. *Damage to rotating parts from passage of current.*—The damage to rotating parts may be serious where a heavy current must pass through an important bearing. Discharges with currents as high as 100,000 amperes showed no appreciable damage on the main bearing, or upon ball bearings. Since this discharge lasted for a fraction of a microsecond only, the tests do not prove that damage from this source can be entirely ignored. In general, however, it would seem that a discharge striking

a metal propeller would flash from the shaft to the face of the engine case without causing any damage. However, should the discharge take place in the bearing, it is possible that trouble would result. Owing to the resistance of the bearing, it is comparatively easy to provide a shunt path between the propeller shaft and housing so that the oil film will not be punctured by a discharge.

While the energy stored in the test condenser is of the order of 10,000 watt-seconds compared to 10,000,000 watt-seconds in the discharge of lightning, it must be remembered that the energy is dissipated almost entirely in heating the air so that the energy dissipated in a bearing may not be any more with a lightning stroke than that under laboratory conditions, unless the discharge consists of a number in rapid succession liberating a considerable amount of energy.

8. *Sudden change in pressure on adjacent surfaces.*—The sudden change in air pressure following a heavy stroke will probably not exceed that frequently occurring under normal flight. Should a discharge be close to and parallel a surface, it is possible that a heavy effective pressure may be set up tending to cause the collapse of same. It is this sudden change in pressure which probably accounts for the tearing of fabric.

It is evident that the larger the spread of the conducting surfaces the greater will be the danger of a stroke including the airplane in its path to ground, or from cloud to cloud. While the use of an aerial extending some distance below the plane will tend to increase the danger of a stroke it must be remembered that this will at least keep one of the points of contact of the discharge at some distance from the plane. This advantage may more than offset the increased probability of a strike. The use of a loop set does not change the hazard in any way over that where no radio set is used. The use of a strut or mast extending above the plane for an aerial would seem to be an added protection as it would tend to keep the point of contact at a distance.

The insertion of a resistane or impedance between the antennæ and instrument with a shunt path to the frame of the aircraft will provide ample protection, the protection probably being much more effective than that provided for the ordinary house radio set using an outside aerial.

While hot gas is a good conductor, the question of the engine exhaust forming a conducting path which would tend to induce a stroke to the plane does not seem to be an appreciable hazard. In all of the tests the effect of the exhaust gases could not be noticed. In the many tests made there was no indication that a low resistance or conducting path was created by the hot gases. In fact, it would appear that the dielectric strength of the air was apparently increased by the wind or pressure produced by the propeller. While the gases are conducting for a very short distance from the exhaust, this hot gas is soon cooled by the mixing of the strong air current produced by the propeller, so that no effect upon a discharge can be expected.

In conclusion it may be said that while information is lacking as to the effect upon the person, much can be accomplished to remove the danger of this effect by giving attention to the various factors involved. While the hazard is exceedingly small, it is possible that still further improvements may be effected by taking advantage as opportunities in design and construction present themselves.

Further information upon the effect of shock will doubtless show that the hazard is not very great, although



it may appear to be necessary to protect the pilot from sound or other conditions during a storm. Where the pilot has a fear of lightning, it is possible that tests or checks might be devised which would remove this fear.

Anything which will permit the safe landing of the plane or provide automatic control while the pilot is

stunned would do much to eliminate the hazard that now exists. Owing to the increased reliability of aircraft, less attention will be paid to storms. While this will tend to increase the lightning hazard, it would seem that the present hazards can be more than offset by careful attention to the various factors tending to produce reliability.

## OBSERVATIONS FROM AIRPLANES OF CLOUD AND FOG CONDITIONS ALONG THE SOUTHERN CALIFORNIA COAST

By JOSEPH B. ANDERSON, Lieutenant, United States Navy

[United States Naval Air Station, Anacostia, D. C., July, 1931]

While serving as aerological officer of the aircraft squadron, Battle Fleet, at the fleet air base, San Diego, Calif., during the summers and autumns of 1928 and 1929, many previously formed ideas of the California weather underwent a considerable change. Perhaps the most interesting of these was that, in so far as aerological officers and aviators are concerned, the weather lacks much of the regularity which had been expected from the claims of the Californians and descriptions of tourists. It is true that over the land adjacent to the ocean there is little rain during the summer, few thunderstorms and gales, and that the sky generally becomes cloudy during the night with clouds that burn off early the next morning, leaving the day more or less cloudless. (At sea the clouds may, or may not burn off, a fact of little concern to those on land but often vitally important to the aviator and navigator.) With this the regularity ceases, for the velo<sup>1</sup> clouds frequently form over land as early as 2 or 3 p. m., and continue until early morning, mid forenoon, or even until noon, at heights which vary from 1,000 to 4,000 feet, according to conditions. If the clouds form at an altitude of 2,000 feet or more, they are of little moment to the pilots of aircraft. However, when they develop at such an altitude that their bases are less than 1,000 feet, there is a considerable likelihood that they will continue to lower until they reach the surface, when, to all practical purposes, a dense fog results.

Since the flight operations are often delayed, cut short, and even rendered impossible by a velo cloud that fails to burn off at the usual time, or that forms earlier than the regular time, the aerological officer receives many inquiries from squadron commanders asking the time the sky will clear, the time that the clouds will form at night, what the ceiling will be, whether night flying is advisable, if the clouds will clear at sea during the day, and many similar questions. Obviously the answers to these questions are not always apparent.

During the summers of 1928 and 1929 many schemes were adopted in an effort to find the why and the wherefore of the southern California coast weather in the belief that if they were found, the when could be more easily determined. The current weather maps were available but did not explain many of the observed details. Old maps were studied in an attempt to classify them in accordance with certain very definite types of weather which were observed, but with little success. A study of the actual changes in the weather during these types proved to be more fruitful of results and accounted for many of the successful forecasts; but at times a very definite type would change suddenly, apparently without cause, and a more or less complete failure in the forecast would result. The lack of reports from the south and west made the identification of fronts difficult, and even impossible, much of the time. Further, meteorological

literature was searched for a satisfactory explanation of presence of the velo cloud during the night and its absence during the day, at least over land. The explanations found did not appear to be of great practical value in forecasting the cloud conditions.

There remained, however, the aerograph records which had been made during the many aerological flights at the naval air station, and the opinion was soon formed that if an understanding of the velo cloud, and its many changes, were to be gained it would be from the visual observations and instrumental records obtained during flight. As stated, there were many records available, but these did not seem to give the detailed information desired. Practically all records made during the summer and autumn months showed that a temperature inversion existed over the air station during these seasons, and other records showed that the inversion was frequently present during the other seasons. This, of course, was already well known, as were the several theories which had been advanced to explain the cause of this condition, such as the Imperial Valley air theory and the settling air, or subsidence, theory. (The former states that the warm, dry air above the base of the temperature inversion<sup>2</sup> is air which has moved westward over the mountains from the Imperial Valley to the coast, while the latter explains the temperature and dryness of the upper air as due to the presence of the HIGH in the upper atmosphere over the semi-permanent thermal LOW at the surface in Lower California. The slow descent of air from this HIGH is given as the cause for the heat and dryness aloft.) The main points noted in the old records were that the temperature of the air decreased rapidly with the altitude until the base of the inversion was reached, then the temperature increased with continued increase in elevation to some definite point above which a more or less normal decrease in temperature occurred. The record showed that as a general condition the relative humidity increased from the surface to the base above which it decreased rapidly, usually to 50 per cent, or less; often to between 50 and 25 per cent; again, to less than 25 per cent; and occasionally to almost 0 per cent. However, it was found from observations during some of the aerological flights that there were inaccuracies in the temperature and relative humidity traces on the older records and also on the ones being made during the early summer of 1928. The inaccuracies in the relative humidity traces were caused by the type of humidity element installed on the aerograph, a type much too sluggish to record details during a routine climb. The temperature inaccuracies referred to were caused by the frequent delays in take off when the sun was shining. Experience showed that unless especial precaution were taken under these conditions a temperature of 2° to 5° C. above the true air temperature would be recorded at the time of the

<sup>1</sup> Velo cloud, the name given by Californians to the high fog or stratus cloud that drifts over land and generally burns off as the day advances.—Editor.

<sup>2</sup> For the sake of brevity the word "base" alone will be used on subsequent pages, the meaning in all cases being the same as in the present instance.